Int J Life Cycle Assess (2011) 16:599–610
DOI 10.1007/s11367-011-0304-8

LCA FOR FOOD PRODUCTS

Environmental assessment of the Atlantic mackerel (*Scomber scombrus*) season in the Basque Country. Increasing the timeline delimitation in fishery LCA studies

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Received: 20 January 2011 / Accepted: 11 May 2011 / Published online: 25 May 2011
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Abstract
Purpose The purpose of this study was to evaluate the environmental impacts linked to fish extraction on a temporal basis, in order to analyze the effect that stock abundance variations may have on reporting environmental burdens. Inventory data for the North-East Atlantic Mackerel (NEAM) fishing season were collected over an 8-year period and used to carry out a life cycle assessment (LCA). The selected fishery corresponds to the Basque coastal purse seining fleet.
Materials and methods The functional unit (FU) was set as 1 t of landed round fish in a Basque port during the NEAM fishing season for each of the selected years. The selected data for the life cycle inventory were gathered from personal communication from ship owners and from a fish first sale register in the Basque Country. A series of fishery-specific impact categories and indicators were included in the evaluation together with conventional impact categories.
Results and discussion Conventional LCA impact categories showed that the environmental impact is dominated by the energy use in the fishery, despite of the low fuel effort identified with respect to other purse-seining fisheries. Nevertheless, strong differences were identified between annual environmental impacts, attributed mainly to remarkable variations in NEAM stock abundance from 1 year to another, whereas the fishing effort remained relatively stable throughout the assessed years. Fishery-specific categories, such as the discard rate or seafloor impact showed reduced impacts of this fishery respect to other small pelagic fish fisheries. Finally, the fishery in balance (FiB) index identified the evolution of NEAM stock abundance for this particular fishery.
Conclusion To our knowledge, this is the first fishery LCA study in which there is sufficient inventory data in order to conduct the methodology throughout a wide period of time. The outstanding variance in environmental impacts from one season to another evidences the need to expand fishery LCAs in time, in order to attain a more integrated perspective of the environmental performance of a certain fishery or species.

The extension of LCA inventories in the timeline may be an important improvement for activities that rely entirely on the extraction of organisms from wild ecosystems. For instance, future research will have to determine the importance of increasing the timeline in fishery LCAs for species that do not show large stock abundance variations through time, unlike NEAM.

Keywords Atlantic mackerel · Life cycle assessment · Purse seining · *Scomber scombrus* · Timeline analysis

Electronic supplementary material The online version of this article (doi:10.1007/s11367-011-0304-8) contains supplementary material, which is available to authorized users.

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1 Introduction

The Basque country has traditionally been an important fishing region at a European level since late medieval

times, when whale fishing was an important industry and the first transatlantic vessels started commercializing cod fished in Newfoundland (Macías-Pereda and Muruaga 1992). Currently, the importance of the Basque fishing fleet has not diminished, but fleet characteristics and target species have shifted considerably due to the depletion or overexploitation of many traditional fisheries (Pauly et al. 2002; Worm and Myers 2004; SOFIA 2008).

The Basque fishing fleet is made up of a coastal fleet that targets small pelagic fish, a cod trawling fleet, an offshore trawling fleet that targets hake in the Northern (ICES Divisions VIIIabd and VII) and Southern stocks (ICES Divisions VIIIc) and, finally, a strong tuna industry made up of 24 vessels (Table 1). Despite of the strong reduction in the number of vessels, tonnage and overall landings in the past few years, the importance of this fleet is obvious since its current total gross tonnage (GT) is comparable to that of Denmark, Ireland, or Germany (Murua et al. 2003; EUROSTAT, 2009).

The decrease in landings, however, has not only been affected by the reduction of the fishing fleet forced by the Common Fisheries Policy (CFP), but also by the increasing limits to the total allowable catch (TAC) for certain species such as European hake or by the closure of the anchovy fishery (2005–2009). Within this frame, North-East Atlantic mackerel—NEAM—(*Scomber scombrus* Linnaeus 1758), a pelagic shoaling species belonging to the Scombridae family that is widely distributed in European waters (Punzón et al. 2004; Uriarte et al. 2001), presents itself as the only major target fishing species that has not only maintained, but also increased its landings in recent years. The Basque coastal fleet mainly extracts this species in ICES Division VIIIc in the late winter and early spring months (Table 2), coinciding with the peak of spawning activity in the East and Central Cantabrian Sea (Uriarte and Lucio 2001). Most of the vessels involved in the NEAM season are purse seiners, but other gears that occasionally target this species are handlines, trawls and, to a lesser extent, gillnets.

Table 1 Number of vessels in the Basque fishing fleet (1992–2007). Source: EUSTAT 2010

Fishing fleet	1992	1999	2007
Coastal fleet[a]	399	340	226
Offshore trawlers	107	63	36
Freezer-trawlers	25	5	0
Deep-sea purse seiners	29	29	24
Cod freezer-trawlers	24	8	5
Total Basque fishing fleet	584	445	291

[a] The analyzed purse seiners in this article are included in coastal fleet vessels

NEAM is one of the main pelagic fish species commercialized in Spain. In 2009, 19,400 t of this species were sold fresh across the nation, and 3,000 t were sold canned (Martín-Cerdeño 2009; Ministry of Environment and Spain-MARM 2008). Additionally, it is also used as bait in many long lining and trolling fisheries. NEAM landings in the Basque Country represent approximately 15% of fresh NEAM commercialized in Spain (Mercados 2010). However, it is important to highlight that over 90% of NEAM landed in the Basque Country corresponds to the February–April period, when together with the neighboring region of Cantabria, they represent 90% of national landings and sales (MERCASA 2010).

The apparent robustness of the NEAM fishery in ICES Division VIIIc is reflected by the increasing spawning stock biomass (SSB) pattern in recent years (ICES 2010) and the strong increase in landings, despite the notable reduction in the number of vessels (Fig. 1). Nevertheless, the fishing fleet analyzed in this article is also threatened by overexploitation, mainly due to the failure to comply with the fixed TACs, and the high fishing mortality (F) of NEAM in the Northeastern Atlantic stock (Table 3), which is considered by ICES as a unique stock (ICES 2007a, b). In fact, recent findings suggest that current stock abundance in the southern section (ICES Divisions VIIIc and IXa) may be linked to a variety of hydrographical factors, such as plankton abundance or temperature shifts (Reid 2001; Hannesson 2007). Therefore, the stock increase in this area would be linked to a changing spatial distribution of the species, rather than on a net improvement of the stock.

In an attempt to identify and quantify environmental impacts linked to the industrial aspects of fish extraction, life cycle assessment (LCA) appears as an internationally recognized methodology (Pelletier et al. 2007). Nevertheless, the importance of including innovative methodological improvements in LCA to broaden its scope and shift to a more comprehensive environmental analysis of fisheries is a major concern for LCA seafood practitioners. Consequently, in recent years, there has been a series of publications that have proposed the inclusion of new impact categories in fishery LCA, such as seabed disturbance (Ziegler et al. 2003; Nilsson and Ziegler 2007); biotic resources use (Papatryphon et al. 2004), or discard rate (Ziegler et al. 2009). However, to date, fishery LCA studies have been based on relatively short periods of time—in most cases, one season or year—(Ziegler et al. 2003; Ziegler et al. 2009; Ramos et al. 2010; Vázquez-Rowe et al. 2010b; Vázquez-Rowe et al. 2011b), mainly due to the difficulty of obtaining thorough inventory data for a prolonged period of time (Weidema and Wesnaes 1996; Reap et al. 2008). This situation has lead to LCA publications that have not taken into account the irregular cycles that fisheries may be subject to (Pet et al. 1997), especially for those fish species, mainly small pelagic fish (e.g., NEAM), that suffer

Table 2 Calendar of catches for the Basque coastal purse-seining fleet

Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Atlantic mackerel												
Anchovy												
Albacore												

Atlantic mackerel (*Scomber Scombrus*); Anchovy (*Engraulis encrasicholus*); Albacore (*Thunnus alalunga*).

natural interdecadal abundance fluctuations (Pauly et al. 2002; Fréon et al. 2008).

Therefore, in this study, the main objective is to analyze the NEAM season capture by Basque purse-seining vessels during an extended period of time (2001–2008) with the aim of identifying possible environmental performance variations during the assessed period and including a series of fishery-specific categories or indicators that aid in the understanding of this fishery from an integrated perspective.

2 Materials and methods

2.1 Goal and scope definition

The main goal of this LCA study is to assess the environmental impacts related to NEAM extraction by the Basque coastal purse-seining fleet in the Gulf of Biscay (ICES Division VIIIc) on a temporal basis, in order to analyze how a long period of time may affect the environmental performance of fishing fleets that target species with strong annual stock abundance variation. Therefore, an 8-year period (2001–2008) was set as the timeline in this particular study.

The functional unit (FU) that was selected for this particular research corresponded to 1 t of landed round fish in a Basque port during the NEAM fishing season for each of the selected years. This FU is based on the assumption that the main objective of the study was to compare the environmental profile of one same seasonal fishery that was assessed for an 8-year period. The rationale behind using this FU rather than adopting a product perspective (i.e., exclusively NEAM landings) is linked to the fact that it is more realistic to assess a fishery in terms of the total catch and landings, rather than on the independent landing rates of the targeted species, especially when analyzing and discussing fishery-specific indicators or categories.

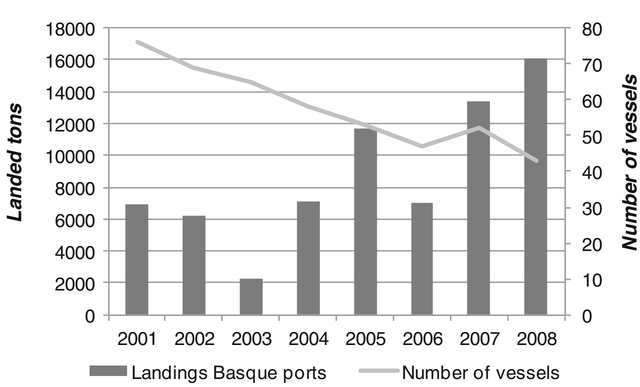


Fig. 1 NEAM landings in the Basque Country in the 2001–2008 period and total amount of vessels in the fishery. Source: ICES; AZTI

The selected fishing fleet was chosen based on the fact that it represented roughly 75% of annual landings of NEAM in Basque ports. The system under study was made up of the different operational stages performed by the assessed coastal purse-seining vessels, including diesel consumption, anti-fouling, marine lubricant oil and trawl net use, and ice consumption. The construction and maintenance of the vessels, as well as cooling agent emissions were also included. However, it is important to note that this study only focuses on the Atlantic mackerel fishing season performed by the selected vessels each year. Therefore, the inventory and the environmental impacts that will be associated to the life cycle inventory (LCI) will only correspond to the assigned resource use and related emissions for the seasonal period that corresponds to NEAM extraction, as will be discussed further on.

NEAM is the main target species, although a series of by-catch species, mainly European pilchard (*Sardina pilchardus* Walbaum 1792), are also landed (Table 4). These species were analyzed ranging from the production of the supply materials until landing operations for sale at Basque ports. Therefore, this assessment constituted a “cradle to gate” analysis (Guinée et al. 2001). The backup for this decision is the fact that on land, seafood operations are not subject to the strong yearly fluctuations that are expected for fishery activities. However, it is important to note that landing operations included only take into account landing operations done on board, while on land operations at port were excluded (Vázquez-Rowe et al. 2010b).

Table 3 Stock assessment summary for the NEAM stock. NEAM catches and TACs for ICES Divs. VIIIc and IXa in the assessed period. Source: ICES

Year	SSB[a]	F	Recruitment[a]	NEAM landings Divs. VIIIc, IXa[a]	Total allowable catch (TAC)	% Over catch respect to TAC
2001	2,138,374	0.40	4,853	43,198	40,180	7.5
2002	1,749,298	0.45	7,854	49,576	41,100	20.6
2003	1,748,701	0.44	3,475	25,823	35,000	−26.2
2004	1,848,672	0.40	4,437	34,840	32,310	7.8
2005	2,290,881	0.28	6,794	49,618	24,870	99.5
2006	2,409,602	0.23	6,915	52,751	26,180	101.5
2007	2,540,759	0.24	3,818	62,834	29,610	112.2
2008	2,709,395	0.23	4,507	59,859	27,010	121.6

SSB spawning stock biomass, *F* fish mortality

[a] Landings reported in ton

2.2 Data acquisition

The samples used for this study corresponded to a set of purse-seining vessels belonging to the Basque coastal fishing fleet obtained according to availability for the different years, as observed in Table 3. The primary data for fishing vessel operations were obtained mainly from a specific Basque register of fish at first sale provided by the Marine Research Division at AZTI. Landings, vessel characteristics (beam, GT, etc.), fishing operations, and fishing areas were the most relevant data obtained from the register. It is important to highlight that data from this register were obtained through a series of questionnaires filled out by AZTI observers, in direct collaboration with skippers from the most important purse-seining ports in the Basque country. The response rate to these questionnaires can be observed in Table 4. A series of additional information, such as the number of seine nets used per vessel or the consumed ice were obtained through personal communication from Basque fishermen and skippers (J.A. Luzarraga, ship owner, personal communication, November, 2010). Cooling agent emissions were provided by AZTI's Marine Research Division (Aboitiz and Pereira 2009; Xabier Aboitiz 2011, personal communication). Finally, background data associated with the production of diesel, nets or anti-fouling, and boat paint were obtained from the ecoinvent database (Frischknecht et al. 2007).

2.3 Life cycle inventory

The development of the LCI involves the collection and computation of the data in order to quantify the relevant inputs and outputs in the production system, including resource usage and emissions related to the analyzed system (ISO 2006). This phase is usually the most time-consuming compared to other LCA phases, mainly due to the difficulty in collecting comprehensive data. Hence, this last issue is probably the main responsible for the scarce appearance of long period analysis in fisheries LCA, together with the fact that this methodology has only been implemented recently in this field. Therefore, data in this study were collected for an increased period of time, in order to achieve a reliable and representative picture of the environmental performance of the analyzed system.

A simplified inventory summary regarding the main inputs and outputs of the studied system is shown in Table 5, while additional data were given in Online Resource 1. Inventory data relating to NEAM landings were obtained from a range of 27–45 purse seiners depending on the assessed year, representing at least 40% of the total purse-seining fleet (see Table 3). Unfortunately, only six vessels were assessed for the entire period, due to vessel scrapping in order to meet CFP regulations and lack of data availability for certain years.

Table 4 Selected vessel samples for the 2001–2008 period

	2001	2002	2003	2004	2005	2006	2007	2008
Sample size	35	28	30	31	41	27	45	35
% Over total fleet	46.1	40.6	46.2	53.4	77.4	57.4	86.5	81.4
Average beam (m)	29.2	28.0	27.2	30.8	31.6	33.0	32.3	32.1
Average daily capture by vessel (tons)	5.77	5.94	2.04	6.76	11.16	10.02	17.82	22.13
Total NEAM landings (tons)	3,222	2,286	164	2,990	7,255	2,897	10,171	11,394
% Over total NEAM landings	63.3	68.9	36.9	77.2	96.9	87.8	99.6	97.3
% Of NEAM landings over total	79.8	85.8	33.4	83.9	93.3	89.3	97.6	98.1

Table 5 Inventory for fish landed in the NEAM season in Basque ports by coastal purse seiners in selected years of the 2001–2008 period

Inputs				
From the technosphere				
Materials and fuels	Units	2001	2004	2008
Diesel	kg	31.53	34.63	14.62
Steel	kg	7.01	9.80	7.15
Anti-fouling	g	884	1,249	931
Boat paint	g	310	440	332
Marine lubricant oil	g	80.0	87.8	37.1
Ice	kg	125.0	125.2	122.6
Seine net (nylon+ lead+cork)	kg	3.68	3.69	2.65
Outputs				
To the technosphere				
Products				
Total round fish	t	1	1	1
NEAM	t	0.798	0.839	0.981
Other pelagic fish	t	0.202	0.161	0.019
To the environment				
Emissions to the atmosphere				
1. CO_2	kg	100.0	109.8	46.33
2. SO_2	g	315	346	146
3. VOC	g	75.7	83.1	35.1
4. NO_x	kg	2.27	2.49	1.05
5. CO	g	233	256	108
6. R22	g	4.08	4.52	3.40
Emissions to the ocean				
1. Xylene	g	80.9	114.4	85.2
2. Dicopper oxides	g	183	259	193
3. Zinc oxides	g	82.8	117.1	87.2
4. Nylon	g	421	423	304
5. Lead	g	93.2	93.5	67.3

Data per FU: 1 t of landed round fish during the NEAM season

Discard amounts were not available for this fleet. Nevertheless, discussion on average ranges relating to discards in these types of fisheries was included. The seafloor impact potential (SIP) proposed by Nilsson and Ziegler (2007) was assumed to be minimal for the gear used by this particular fleet. Nevertheless, this issue will be analyzed in the discussion section.

2.4 Allocation strategies and other assumptions

The purse-seining fishing fleet under study presents three distinct fishing seasons, as mentioned in Table 2. The first two seasons of the year, the NEAM and the anchovy season, take place in the first half of the year, while the albacore fishing season takes place throughout the second half of the year. Therefore, temporal allocation for construction and maintenance materials in the LCI was performed by assigning half of the annual inputs/outputs to the albacore season, while the other half was assigned proportionally to the other two fishing seasons depending on their annual length. It is important to note that this procedure is influenced by the fact that the anchovy fishery has suffered strong restrictions or closure in recent years (ICES 2009). Additionally, the same procedure was implemented to allocate cooling agent emissions to the studied fishing season.

No further allocations were needed in the selected case study due to the characteristics of the chosen FU. In other words, the fact that NEAM and by-catch are analyzed globally in terms of total landings makes it possible to disregard other allocation procedures, such as mass or economic allocation (Ayer et al. 2007). The rationale for disregarding mass allocation, which would be appropriate due to the similar economic value of the by-catch (mainly sardine landings) when compared to NEAM, is linked to the fact that it is more realistic to assess a fishery in terms of the total catch and landings, rather than on the independent landing rates of the targeted species, especially when analyzing and discussing fishery-specific indicators or categories. Additionally, the highly specialized NEAM fishing season involves low by-catch rates. For instance, as seen in Fig. 2, NEAM landings represent at least 80% of the total catches during the NEAM fishing season in all the assessed years, except for the year 2003, coinciding with the Prestige oil spill, in which NEAM landings represented only 33% of the total.

2.5 Impact category selection

CML baseline 2000 method was selected as the computational framework for the attributional (retrospective) LCA analysis (Heijungs et al. 1992; Guinée et al. 2001). The impact categories that were included in the assessment were: Abiotic Depletion Potential (ADP), Acidification

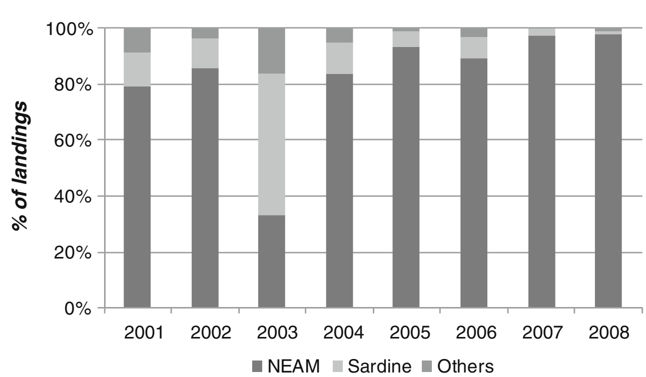


Fig. 2 Relative landings of selected fishing species by the Basque purse-seining fleet in the assessed fishing seasons

Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP), Ozone Layer Depletion Potential (ODP), and Marine Aquatic Ecotoxicity Potential (METP). The software that was used for the computational implementation of the inventories was Simapro 7 (PRè-Product Ecology 2011). Additionally, a series of fishery-specific categories were discussed in this research, including discard reporting, SIP as proposed by Nilsson and Ziegler (2007), and the fisheries in balance (FiB) index as proposed by Pauly et al. (1998). The FiB index aims at identifying the *fishing down marine food webs* phenomenon, which suggests that when fish species at the top of the trophic chain are overexploited, the captures of species lower down in the trophic level increase (Pauly et al. 1998; Villasante 2009).

3 Results

3.1 Characterization results identified on a temporal basis for landings during the NEAM season

Vessel operations were the main activities linked to fish extraction in the NEAM season that contributed to the environmental impact in all the conventional impact categories assessed, except for ODP, in which no environmental emissions were generated by this subsystem, and ADP. Nevertheless, a series of differences were found between the evaluated years. For instance, for GWP contributions ranged from 48% in the year 2002, to 62% in 2004, while contributions to METP were in all years above 83% (year 2001). Diesel consumption was identified as the main contributor to environmental impact within vessel operations for all the impact categories, except for METP in which the main burden was linked to anti-fouling emissions to the ocean.

For the ADP impact category, the main environmental burdens were linked to the diesel production subsystem. For this particular activity, impacts ranged from 54% in 2002 to 71% in 2004. The relative contribution of diesel production to the other impact categories was, in all cases, below 10%.

ODP relative contributions were overwhelmingly related to cooling agent emissions by the refrigeration systems on board. Their contribution to this impact category was at least 90% (years 2001 and 2004). Additionally, cooling agents (mainly R22), also presented relevant environmental impacts for GWP, ranging from 4% in 2001 to 9% in 2003.

Finally, the net production and transportation subsystem also appeared as an important contributor in the ADP and GWP categories, with values ranging from 17% in 2004 to 34% in 2002 for ADP and from 14% in 2004 to 29% in 2002 for GWP. Other relevant activities or processes regarding environmental impact were the ice production system and, to a lesser extent, operations relating to the construction and maintenance of the vessels (anti-fouling and steel production). More detailed data on individual contributions per activity may be consulted in Online Resource 2.

When the total environmental burdens for the different seasons are compared, as can be observed in Fig. 3, 2008 appears as the year with lowest associated burdens per FU for all impact categories, except for METP. The lowest impacts for the average vessel for METP were achieved in the year 2001. On the contrary, the season in 2003 had the highest associated impacts for all impact categories.

If the season in 2001 is taken as the reference, since it is the first assessed period in the selected time scale, a high oscillation in the environmental impacts can be observed from one season to another. On the other hand, the NEAM season in year 2003 shows environmental impacts at least 130% higher respect to the reference year (AP), while in some impact categories, it is 324% higher (METP). Additionally, other NEAM seasons in which the associated burdens are above those registered for 2001 are 2002, 2004, and 2006.

On the other hand, the NEAM seasons in years 2005, 2007, and 2008 showed reduced environmental impacts when compared to the reference year. The lowest impacts corresponded to year 2008, in which the associated burdens were, for example, 43% lower than in the reference year for ADP and GWP. The results for years 2005 and 2007 were very similar, with environmental impacts ranging from 19% to 27% less than in the year 2001 for ADP, AP, EP, and GWP.

3.2 Fishery-specific environmental impacts

Discard data were not available in this fleet for any of the assessed years. Nevertheless, according to a series of personal communications in Basque ports, skippers and fishermen confirmed that the discards generated through captures in the NEAM season by the Basque purse-seining fleet are close to the average 1.6% reported by Kelleher (2005) for pelagic purse-seining fisheries (J. Ruiz, marine researcher, personal communication, November 3, 2010).

As observed in Fig. 4, the FiB index shows a strong decline in the 2001–2003 period, a relatively stable period from 2004 to 2006 and a moderate increase in the final 2 years of the study. The year with the strongest fall in the index was 2003, in which the decrease was above 1, while 2008 appeared as the year with highest increase in the FiB index (0.26). These results are in accordance with the mean trophic level (MTL) observed in the different years (Fig. 4), showing, in the first place, a strong decline in the 2001–2003 period and, secondly, a quick recovery and stabiliza-

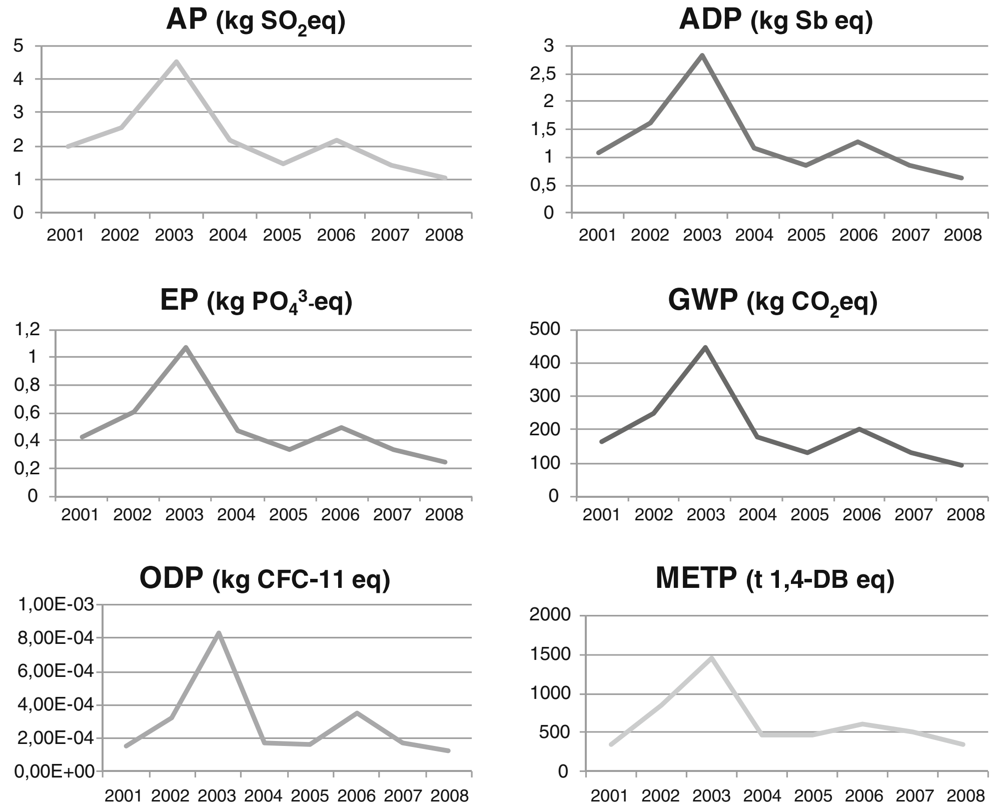


Fig. 3 Environmental impact potentials for the average vessel per FU in the assessed period

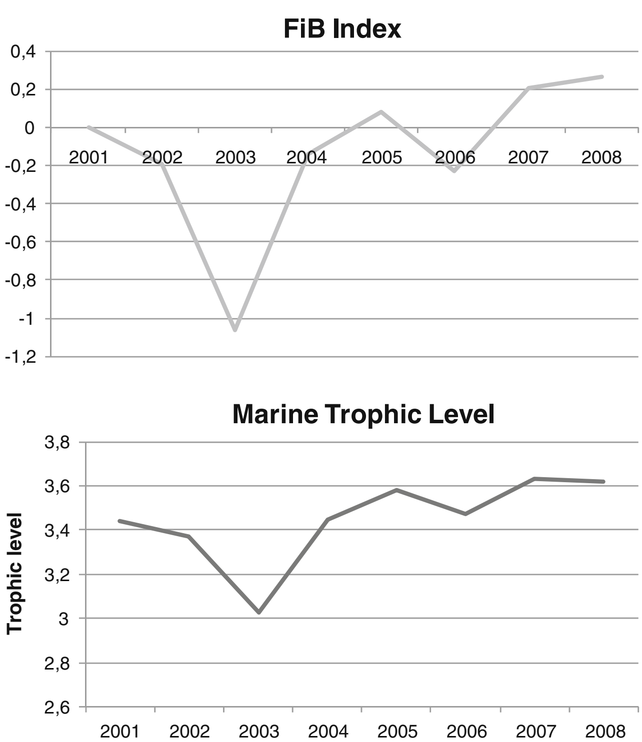


Fig. 4 **a** FiB index for the Basque NEAM season (years 2001–2008). **b** Calculated MTL for the Basque captures during the NEAM season (years 2001–2008)

tion at a trophic level of around 3.6 until 2008. This tendency would translate in a 0.225 increase in the trophic level per decade.

4 Discussion

4.1 The importance of applying fisheries LCA for a significant extent of time

Environmental burdens related to the landing of 1 t of pelagic fish in Basque ports show similar trends to other landings fished by purse seiners in other fisheries (Thrane 2004; Hospido and Tyedmers 2005; Vázquez-Rowe et al. 2010b), despite the increased variance that was observed between the selected years. Furthermore, due to the reduced fuel consumption of the analyzed fleet during the NEAM season, fuel-related vessel operations only represented from 48% (2002) to 62% (2004) of the total environmental impact for GWP. Therefore, the importance of other vessel subsystems, such as net or ice production is greater than in other fleets that are more fuel intensive (Thrane 2004; Vázquez-Rowe et al. 2010a, Vázquez-Rowe et al. 2011b).

Nevertheless, the fact that this study comprises a relatively long period of time shows that there can be a

great difference in the environmental burdens for a given impact category from 1 year to another. For instance, regarding GWP, the associated environmental impact per FU in the year 2003 was of 445 kg CO_2 eq, 4.68 times more than in 2008 (95 kg CO_2 eq). This tendency was observed for all the conventional impact categories that were included in this study, highlighting the importance of extending LCA inventories to wider periods of time, in order to obtain a broader perspective of the impacts associated to a particular fishery.

Additionally, this improvement may be extremely useful for those species that show erratic biomass and fecundity patterns (Fréon et al. 2008) or for those species that are under recovering schemes in depleted fisheries, since stock abundance variations and fishing overcapacity may generate a context that triggers fluctuations in environmental impact per FU.

The particular circumstances that surround fisheries as an industrial system make them unpredictable, since they are majorly dependent on fish abundance in a given period of time and a given spatial distribution. Other factors that may influence a fishery, such as management policies, are just a consequence of guaranteeing the sustainability of a limited resource (Clover 2006). Therefore, the extension of LCA inventories in the timeline may be an important improvement for activities that rely entirely on the extraction of organisms from wild ecosystems (Hospido and Tyedmers 2005).

Furthermore, an extended timeline in fishery LCAs not only allows identifying tendencies in a particular fishery, but may also help detect specific circumstances that create a brusque variation in LCA characterization values. For instance, the outstandingly high environmental impact results attained by in the 2003 NEAM fishing season coincide with the wreck of the oil tanker, Prestige, off the Galician coast (November 19, 2002), which affected great part of the surface in the Cantabrian Sea shelf. In fact, Sánchez et al. (2006) identified significant reductions in the abundance of megrim (*Lepidorhombus boscii*), Norway lobster (*Nephrops norvegicus*), and Pandalid shrimp (*Plesionika heterocarpus*) during the year 2003, with noteworthy recoveries during the 2004 season. Despite the fact that none of these species are pelagic, it is highly probable that NEAM suffered similar consequences linked to the oil spill, especially taking into account that during NEAM spawning, which starts usually in late February, there was an elevated presence of oil masses in the Cantabrian Sea continental shelf (Sánchez et al. 2006).

Therefore, obtained results suggest the need to increase the timeframe of fisheries LCA on a regular basis. However, the handling of the results attained when timeline analysis is applied may give rise to biased or incorrect conclusions, due to the increased difficulty linked to multiple result interpretation (Vázquez-Rowe et al. 2010a). Hence, given that yearly results can be somewhat misleading, revealing the need to smoothen out short-term fluctuations at the same time as highlighting longer-term cycles, a 5-year moving average was proposed (Hamilton 1994), as can be observed in Fig. 5 for the GWP impact category.

4.2 Energy use

In terms of direct fuel consumption in the analyzed fishery, the average consumption ranges from 14.6 kg fuel/t fish in 2008 to 41.1 kg fuel/t fish in 2002, except for the year 2003, in which the energy use rocketed to 75.9 kg fuel/t fish. Therefore, the tendency observed for the assessed years shows that fuel consumption per ton of landed fish has decreased considerably in this period (see Online Resource 1). Recent literature (Schau et al. 2009), suggested that strong declines in this ratio are usually linked with important increases in the fuel price. However, the low fuel consumption linked to this fishery makes the fleet less sensitive to the fluctuations in fuel price. In fact, the increase in the amount of landings per day and vessel (see Table 4), as well as the overall increase in landings for the years that presented lower energy use and environmental impacts (see Fig. 1), suggest that a leading factor influencing the environmental impact in this fishery is fish availability.

Comparison of these results with other studies shows that they are on the lower range of fuel intensity for purse seiners (Tyedmers 2001; Schau et al. 2009; Winther et al. 2009; Driscoll and Tyedmers 2010). More specifically, when the fuel effort of NEAM season landings is compared to that of other NEAM landing fleets, the fuel intensity in the Basque fishery is considerably lower than in other important NEAM fishing regions, such as Galicia, 176 kg of fuel/t NEAM or Norway, 90 kg of fuel/t NEAM

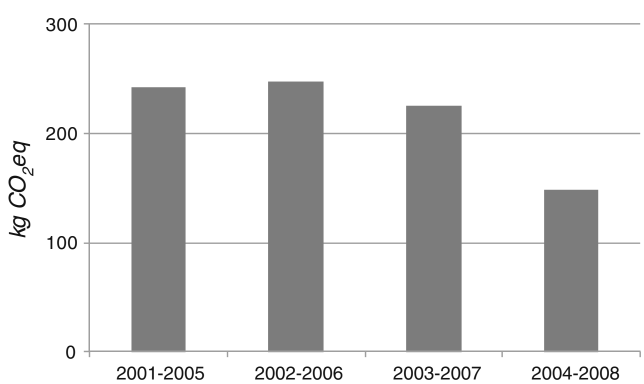


Fig. 5 5-year moving average for the GWP impact category

(Tyedmers 2001; Schau et al. 2009; Vázquez-Rowe et al. 2010b).[1]

The increased fuel intensity reported not only for Galician NEAM landings by purse seiners, but also for NEAM landings regarding the Galician coastal bottom trawling fleet (Vázquez-Rowe et al. 2010b), when compared to those in the Basque Country, evidences the high environmental impact variability between regions showing the risks of reporting LCA results at a national scale for a particular coastal species (Table 6). Additionally, the relevance of studying these spatial variations increases when the fisheries of the analyzed country show independent patterns regarding fishing fleet characteristics and fishery management. It is important to note that results reported in Table 6 for the three fishing fleets are reported for 1 t of landed NEAM following mass allocation.

The main reasons related to this low fuel intensity are mainly linked to the specialized season of NEAM catches in the gulf of Biscay, together with other key factors such as the reduced width of the continental platform in this area compared to the Galician coast, as well as the prohibition of purse seiners to fish within the Galician Rias, forcing the fishing fleet in that area to target NEAM stocks at an increased distance from the coastline (Ministry of Environment and Spain-MARM 2004).

Table 6 Comparative characterization values for selected impact categories for 1 t of round NEAM in three different Northern Spain fisheries (year=2008)

	Unit	F1	F2	F3
Sample size		35	30	24
Average beam	m	32.1	17	28
Energy use	kg fuel/t fish	14.6	176	496
Impact categories				
ADP	kg Sb eq	0.62	4.99	12.27
AP	kg SO_2	1.04	10.2	27.2
EP	kg PO_4^{3-}	0.24	1.95	4.97
GWP	kg CO_2	94.6	797	2,279
ODP	kg CFC-11 eq	1.24E-4	8.66E-4	7.86E-3
METP	t 1,4DCB	351	226	440
Discards	kg/FU	16.3	33.1	727
SIP	km^2	0	0	0.68

ADP abiotic depletion potential, *AP* acidification potential, *EP* eutrofication potential, *GWP* global warming potential, *SIP* seafloor impact potential, *F1* Basque purse-seining fleet, *F2* Galician coastal purse seining, *F3* Galician coastal bottom trawling fleet

4.3 Environmental impacts identified through fishery-specific impact assessment

The inclusion of fishery-specific results in LCA studies, as mentioned above, is a growing concern. However, in this particular research study, the lack of specific discard data for the assessed fishery may have skewed the fishery-specific impact categories to a certain extent. Nevertheless, other publications relating to discards in pelagic fisheries in NW Spain, together with Basque skippers and fishermen comments, suggest that the discard rate for the NEAM season is very low. In fact, Vázquez-Rowe et al. (2011a) reported a discard rate of 3.2% for the Galician purse-seining fleet targeting NEAM, horse mackerel, and sardines, while Kelleher (2005) reports that seining-linked discards in this area are close to the estimated 1.6% for this fishing gear worldwide.

SIP was not applied to this fishery, since it was assumed that purse seining is a fishing gear that causes negligible direct damage on the seafloor according to this index, despite the fact that lost nets can potentially create ghost fishing (Brown and Macfayden 2007; ICES Fisheries Technology Committee ICES CM 2000). Additionally, as can be observed in Table 5, NEAM landings performed by trawlers imply a considerable impact on the seafloor, showing that trawling fleets can create an increased impact on benthic ecosystems (Vázquez-Rowe et al. 2010b; Ziegler et al. 2003).

Regarding fishery exploitation, the increasing pattern for MTL (0.225 per decade) is quite remarkable when taking into account that fisheries assessed worldwide present a decreasing MTL (Pauly et al. 1998; Villasante 2009), especially those in which the targeted species are those with a higher trophic level (Branch et al. 2010). This increase is reflected in the FiB index, which shows increasing positive values in the 2005–2008 period, contrasting with a sharp negative value for 2003. This tendency suggests that the increase in landings in the last few years of the assessed timeline is stronger than the net primary productivity may sustain through time or an expansion in the spatial distribution of the fishery (Pauly et al. 1998). The latter does not seem likely, since skippers from the Basque seining fleet reported not having changed their fishing zones in the assessed years.

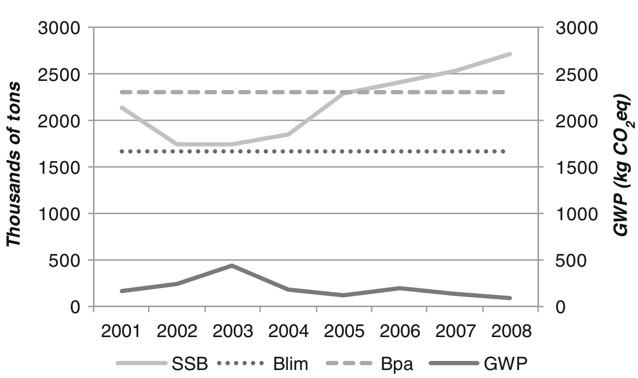
A high number of ecosystems analyzed in previous studies worldwide regarding MTL show that an increase in fish landings is usually linked to higher landings of species with a low trophic level. However, the theory of fishing down marine food webs is not completely valid for this particular case study, mainly because of the fact that at least 79% of the landings of the fishery correspond to NEAM in

[1] The case studies included from the bibliography take into account mass allocation.

each season. Furthermore, taking into account that this study also focuses exclusively on the NEAM fishing season does not make it possible to see the effects that the variable landings of the species may have on other coastal fishing seasons, not only of the coastal purse seining fleet, but also of other fleets that work in the area. Nevertheless, recent studies have identified a clear tendency in the last couple of decades in which the peak of catches for NEAM in the Cantabrian Sea has shifted forward (Punzón and Villamor 2009), a situation that could also have important consequences on the ecosystem and the management of the fishery.

A certain correlation between yearly SSB variations and fluctuations in annual environmental impact for the selected categories was observed for this fishery, as can be observed in Fig. 6. More specifically, the lowest levels of SSB, close to the biomass limit reference point (B_{lim}) are observed in the years with highest environmental impacts (2002–2003), while the lowest impacts for all the selected categories were found in years in which SSB levels were above the biomass precautionary approach reference point (B_{pa}).

The fact that energy use, as mentioned in the previous section, is lowest coinciding with the years with highest captures and SSB, suggests that environmental impacts in pelagic fisheries may be considerably influenced by the availability of fish in a given time period, provided that the vessels' fishing patterns do not experiment significant changes. Nevertheless, a number of factors can influence the obtained results, such as the spatial distribution of the species and fishing management policies (e. g., the fulfillment of the NEAM TAC for Spain may cause increased environmental impacts per functional unit if strict



SSB= spawning stock biomass

GWP= global warming potential

B_{lim}= biomass limit reference point

B_{pa}= biomass precautionary approach reference point

Fig. 6 Annual spawning stock biomass (SSB) for the NEAM stock compared to annual global warming potential (GWP) environmental impacts for the assessed fishing fleet. Source: ICES 2010

daily quotas were to be enforced). Therefore, further research in this field should be taken in order to determine to what extent stock abundance affects the assessed environmental impacts.

Finally, an additional factor that must be taken into account is the fact that the strong increase in stock abundance and landing in the Basque NEAM fishery may cause an increasing building capacity due to the expansion of the resources, which could develop into fleet and industry overcapacity whenever there is a new decline in the resources (Fréon et al. 2008; Villasante 2010; Villasante and Sumaila 2010).

5 Conclusions

To our knowledge, this is the first fishery LCA study in which there is sufficient data in order to conduct the methodology throughout a wide period of time. To date, LCA studies, despite having a broad and praiseworthy work behind when developing the LCI, failed to display the variations in environmental impact that a particular fishery or species could have from 1 year to another. The results obtained in this study suggest the need to increase the timeframe of fisheries LCA on a regular basis when assessing small pelagic species, such as NEAM, since they show strong annual environmental impact variations, in order to increase their feasibility and accurateness. Nevertheless, with the aim to avoid misleading multiple result interpretations, a 5-year moving average is proposed for result reporting. Further research is recommended in order to assess the importance of increasing the timeline in fisheries LCA for those species that show small annual variations in environmental impacts. More specifically, the life cycle environmental impact of NEAM extraction in the Basque Country displayed low environmental impacts per FU, with a similar range to herring landing found in literature. When compared with other fisheries targeting NEAM, such as the Galician coastal seining fleet, the Basque fleet presented environmental impacts up to 88% lower, demonstrating the high regional variability that can be identified within the same country and the risks of reporting fishery LCA results at a national scale.

Finally, the Basque purse seining fleet has shown minimal fishery-specific impacts when regarding discards or seafloor impact. Furthermore, the increasing abundance of NEAM stocks in this area of the Bay of Biscay demonstrates an acceptable state of the stock in its southern area. Nevertheless, the strong increase in landings in the studied period, which has been brought about due to extensive overfishing, may create a future overcapacity of this particular industry (fleet and processing plants) if institutions were to allow an uncontrolled expansion of the sector.

Acknowledgments Saioa Ramos wishes to thank the Basque Government and the Iñaki Goenaga Foundation for financial support. Ian Vázquez-Rowe wishes to thank the Galician Government for the financial support (María Barbeito Program). Furthermore, the authors would like to thank all the anonymous skippers and sailors who kindly agreed to answer the questions proposed in the questionnaires, as well as the team responsible for supplying the requested information from AZTI's marine database.

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